Formal Modeling of Synchronization Methods for Concurrent Objects in Ada 95

Ravi K. Gedela, Sol M. Shatz and Haiping Xu
Department of EECS
Concurrent Software System Lab
The University of Illinois at Chicago
R.Gedela@ericsson.com
{shatz, hxu1}@eecs.uic.edu

Purpose of Formal Methods

"The term "formal methods" denotes software development and analysis activities that entail a degree of mathematical rigor. (…) A formal method manipulates a precise mathematical description of a software system for the purpose of establishing that the system does or does not exhibit some property, which is itself-precisely defined."

(Dillon and Sankar, 1997)

Dillon, L. K. and S. Sankar (1997), Introduction to the Special Issue, *IEEE Transactions on Software Engineering*, Special Issue on Formal Methods in Software Practice, 23(5): 265-266.

Concurrent Program Analysis

- Objects communicate with each other and undesirable situations, such as deadlock or livelock, may occur.
- There are two different types of program fault
  - Unconditional fault
  - Conditional fault
- Automated program analysis is vital for debugging and testing a concurrent program.

Introduction to Petri Net

- "Three-in-one" capability of a Petri net model.
  - Graphical representation
  - Mathematical description
  - Simulation tool
- Definition:

A Petri net is a 4-tuple, PN = (P, T, F, M_0) where

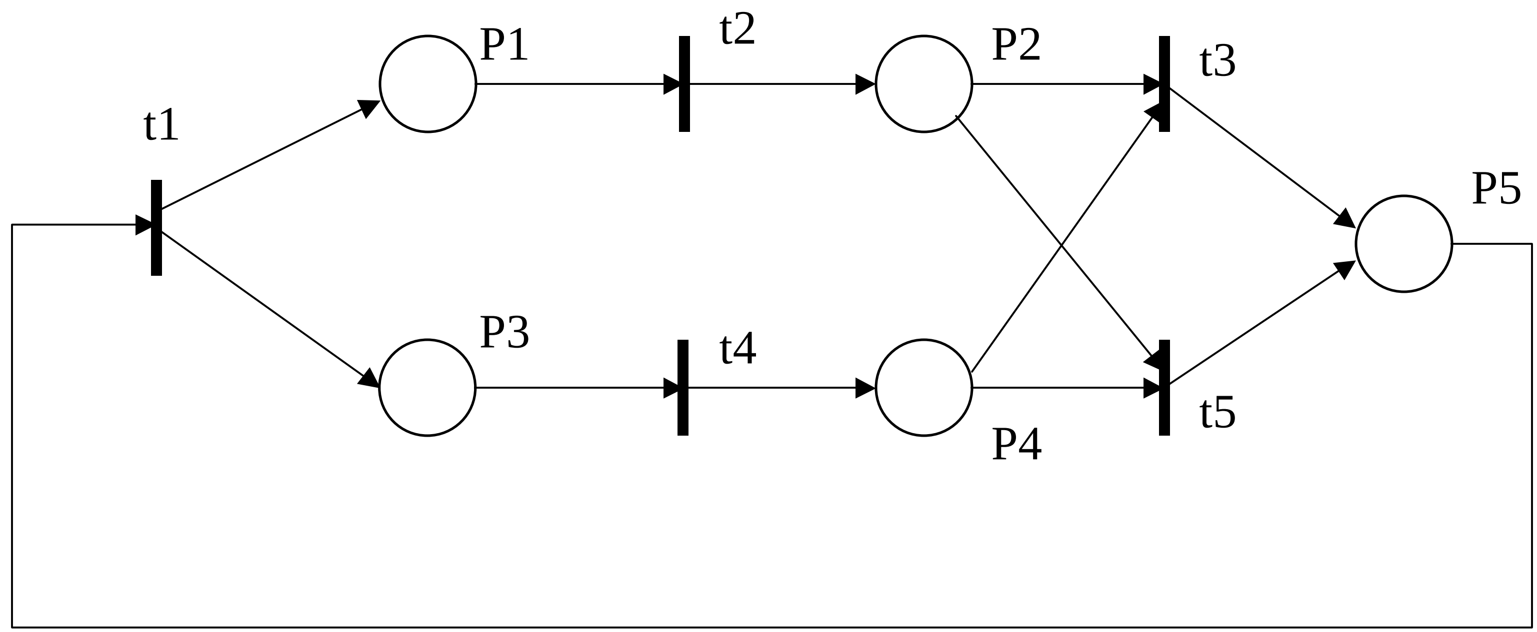
P = {P1, P2, …, Pm} is a finite set of places;

T = {t1, t2, …, tn} is a finite set of transitions;

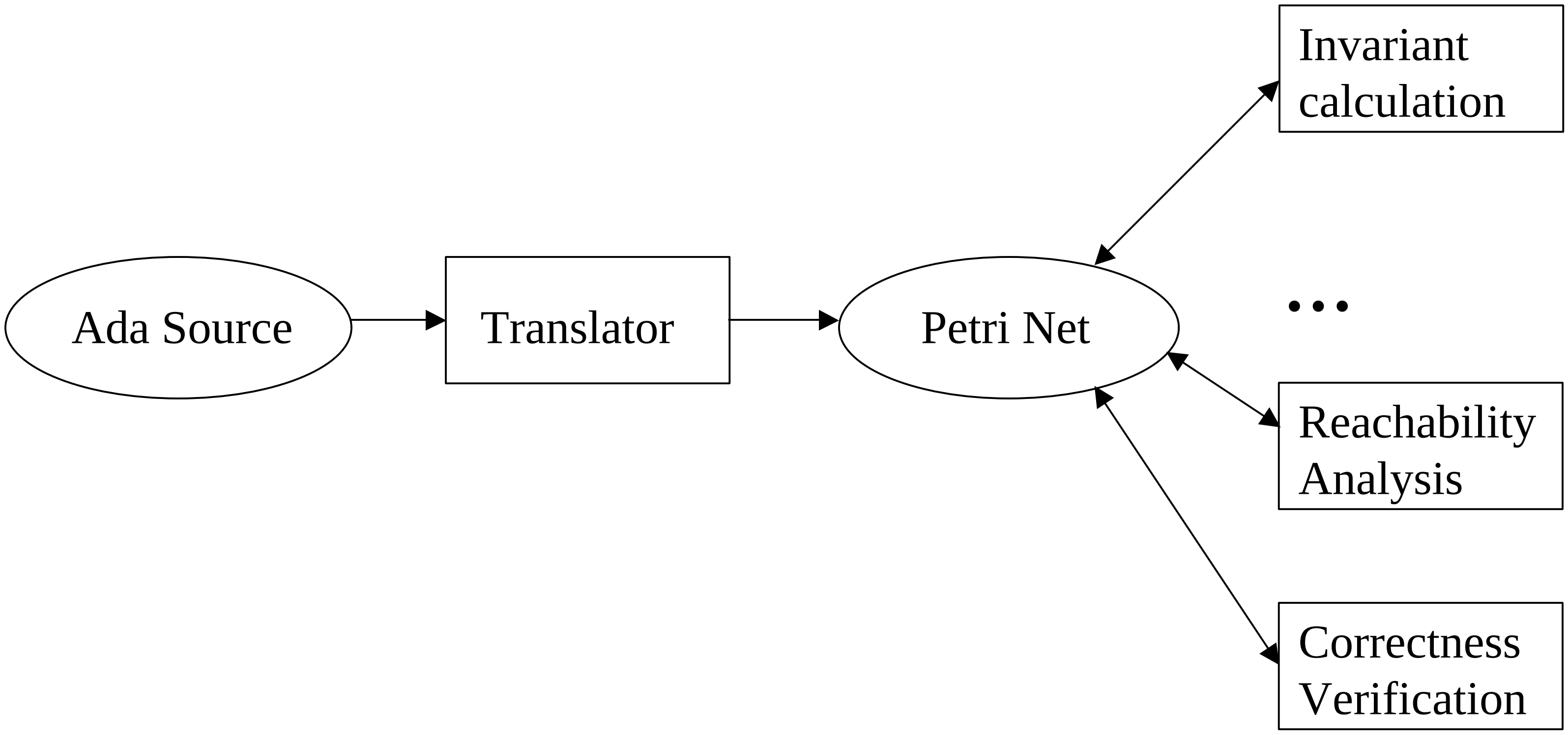
F $\subseteq$ (P x T) $\cup$ (T x P) is a set of arcs (flow relation);

M_0: P --> {0, 1, 2, 3, …} is the initial marking.

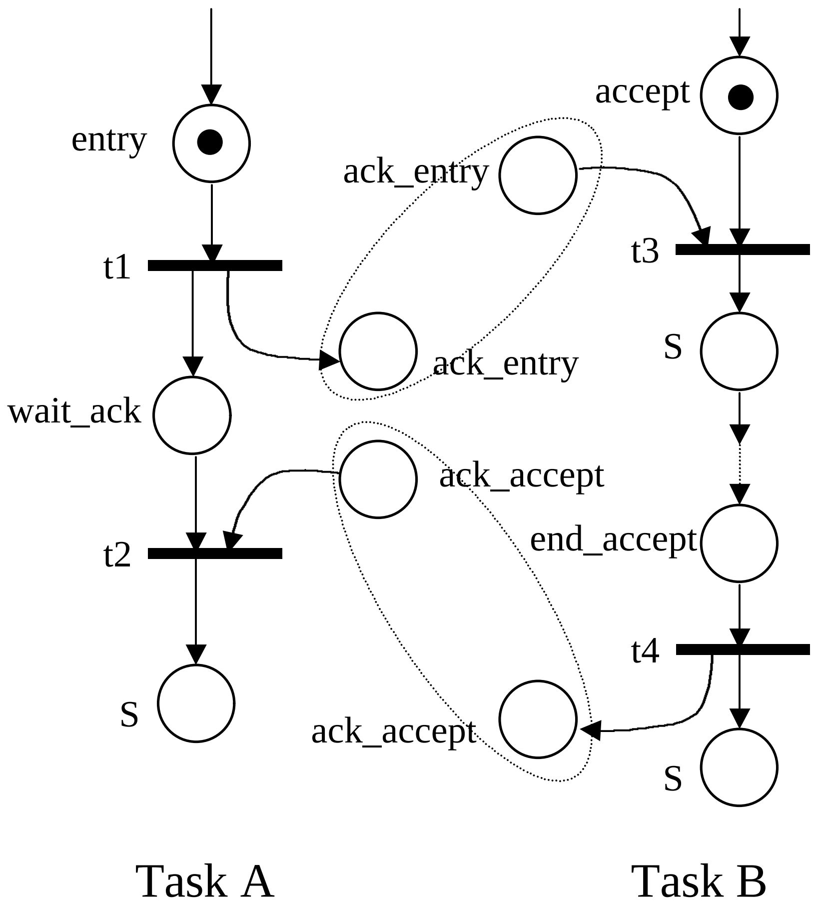
Example:



Automated Program Analysis Paradigm



Example: Modeling Rendezvous



Internal Representation

Task A

entry --> wait_ack, ack_enty

ack_accept, wait_ack --> S

Task B

accept, ack_entry --> S

end_accept --> ack_accept, S

Motivation for This Work

- To illustrate the possibility of translating advanced features of Ada 95 into Petri net.
- To illustrate analysis capability by using a formal modeling tool.
- To provide a graphic viewpoint of synchronization methods to aid understanding for beginner.

Three Synchronization Methods for Concurrent Objects

- Synchronization is added if and when it is required, by extending the object.
- Synchronization is provided by the base (root) object type.
- Synchronization is provided as a separate protected type and the data is passed as a discriminant.

A. Burns and A. Wellings, *Concurrency in Ada*, Cambridge Press, 1995.

Method 1: Synchronization Added by Extending the Object

```
package Object  is
   procedure Op1 (O : in out Obj_Type);
   procedure Op2 (O : in out Obj_Type);
   ...
   type Obj_Type is tagged limited record … end record;
end Object;

package Object.Synchronized is
   type Protected_Type is new Obj_Type with record   L: Mutex;   end
record;
end Object.Synchronized;

protected type Mutex is
   entry  Lock;   procedure Unlock;
end Mutex;
```

Method 1: Synchronization Added by Extending the Object (continue)

```
package  Object.Synchronized.Extended  is
   procedure Op1_ext (O : in out  Extended_Protected_Type);
   procedure Op2_ext (O : in out  Extended_Protected_Type);
   ...
   type Extended_Protected_Type is new Protected_Type
         with record…end  record;
end Object.Synchronized.Extended;

procedure  Op1_ext  (O : in out  Extended_Protected_Type)  is
begin
   O.L.Lock;    Op1 (Obj_Type (O));   O.L.Unlock;
end  Op1_ext;
```

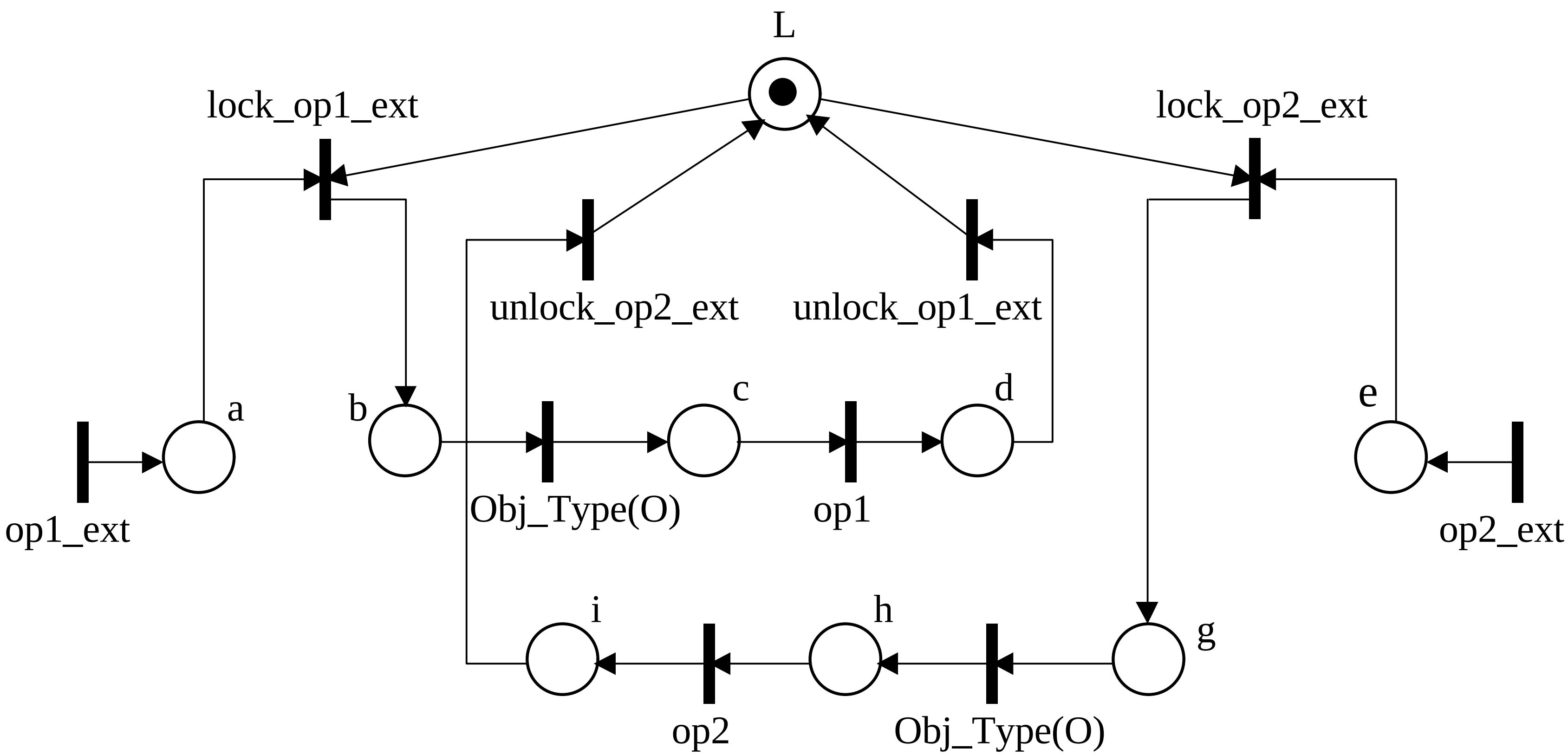


Figure 1. Object.Synchronized.Extended model

Potential Deadlock Problem

```
package Object.Synchronized is
   procedure Op1 (O : in out Protected_Type);
   procedure Op2 (O : in out Protected_Type);
   ...
   type Protected_Type is new Obj_Type with  record   L : Mutex;  end record;
end Object.Synchronized;

procedure Op1 (O : in out Protected_Type) is
begin
   O.L.Lock;  Op1(Obj_Type(O));  O.L.Unlock;
end Op1;
```

Potential Deadlock Problem (continue)

package Object.Synchronized.Extended **is**

procedure Op1_ext (O : in out Extended_Protected_Type);

procedure Op2_ext (O : in out Extended_Protected_Type);

…

type Extended_Protected_Type **is new** Protected_Type **with record…end record**;

end Object.Synchronized.Extended;

procedure Op1_ext (O : **in out** Extended_Protected_Type) **is**

begin

O.L.Lock; **--** *pre_processing*; Op1(Protected_Type (O));

-- *post_processing*; O.L.Unlock;

end Op1;

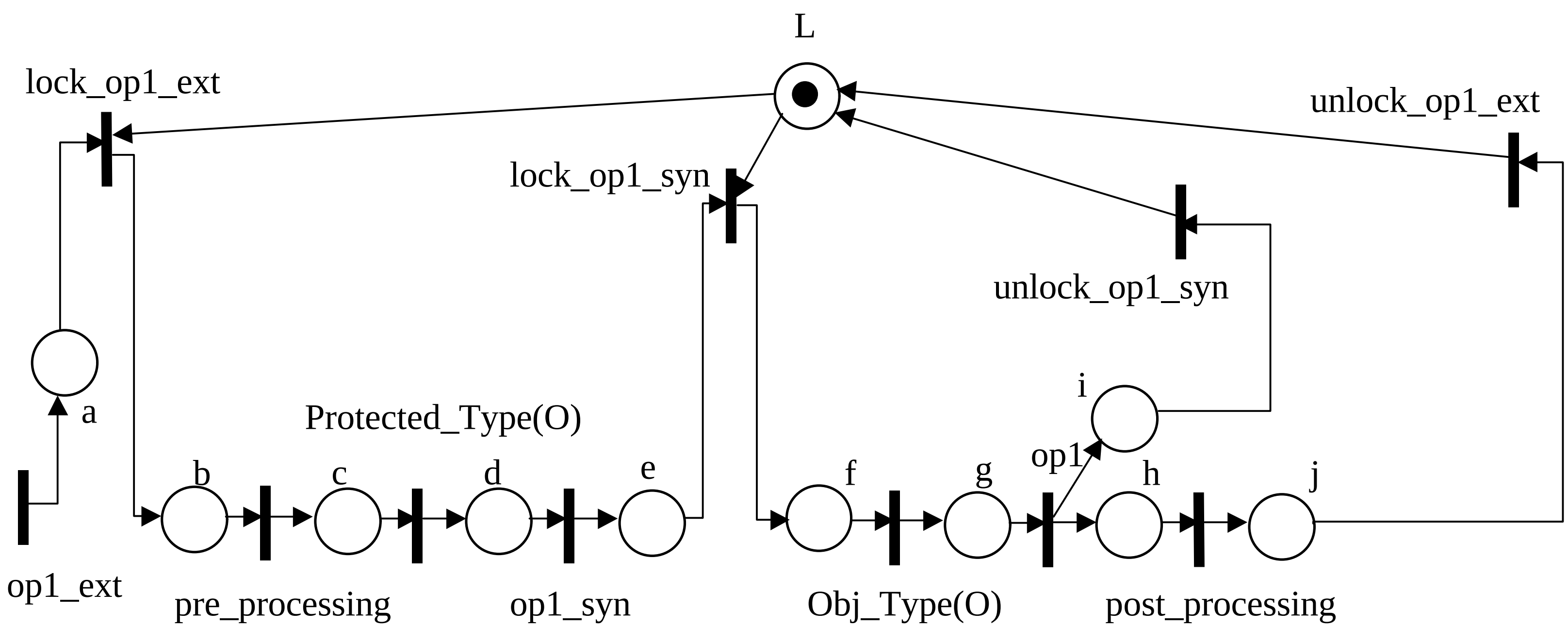


Figure 2. Object.Synchronized.Extended model

Method 2: Synchronization Provided by the Base Object Type

```
package Protected_Object is
   procedure Class_Wide_Op1 (O: in out Protected_Type'Class);
   procedure Class_Wide_Op2 (O: in out Protected_Type'Class);
   ...
   type Protected_Type is abstract tagged limited record  L : Mutex;  end
    record;
   procedure Op1 (O : in out Protected_Type) is abstract;
   procedure Op2 (O : in out Protected_Type) is abstract;
end Protected_Object;

procedure Class_Wide_Op1 (O: in out Protected_Type'Class) is
begin
   O.L.Lock;   Op1(O);  -- dispatch to correct operation   O.L.Unlock;
end Class_Wide_Op1;
```

Method 2: Synchronization Provided by the Base Object Type (continue)

package Protected_Object.My_Object **is**

type My_Object_Type **is new** Protected_Type **with record** … **end record**;

procedure Op1 (O : **in out** My_Object_Type);

procedure Op2 (O : **in out** My_Object_Type);

end Protected_Object.My_Object;

package Protected_Object.My_Object.Extended **is**

type Extended_Protected_Type **is new** My_Object_Type **with record**…**end record**;

procedure Op1 (O : **in out** Extended_Protected_Type);

procedure Op2 (O : **in out** Extended_Protected_Type);

end Protected_Object.My_Object.Extended;

Method 2: Synchronization Provided by the Base Object Type (continue)

MO: My_Object_Type; -- *represented as color M in the following*

Class_Wide_Op1(MO); -- *Petri net model*

…

EP: Extended_Protected_Type; -- *represented as color E in the following*

Class_Wide_Op1(EP); -- *Petri net model*

Notes: We will use colored Petri nets to model this method, where "colored" tokens (or tokens with attributes) are used. In colored Petri nets, a transition becomes enabled when its input places have tokens with attributes that match the inscriptions on the corresponding arcs from the place to the transition.

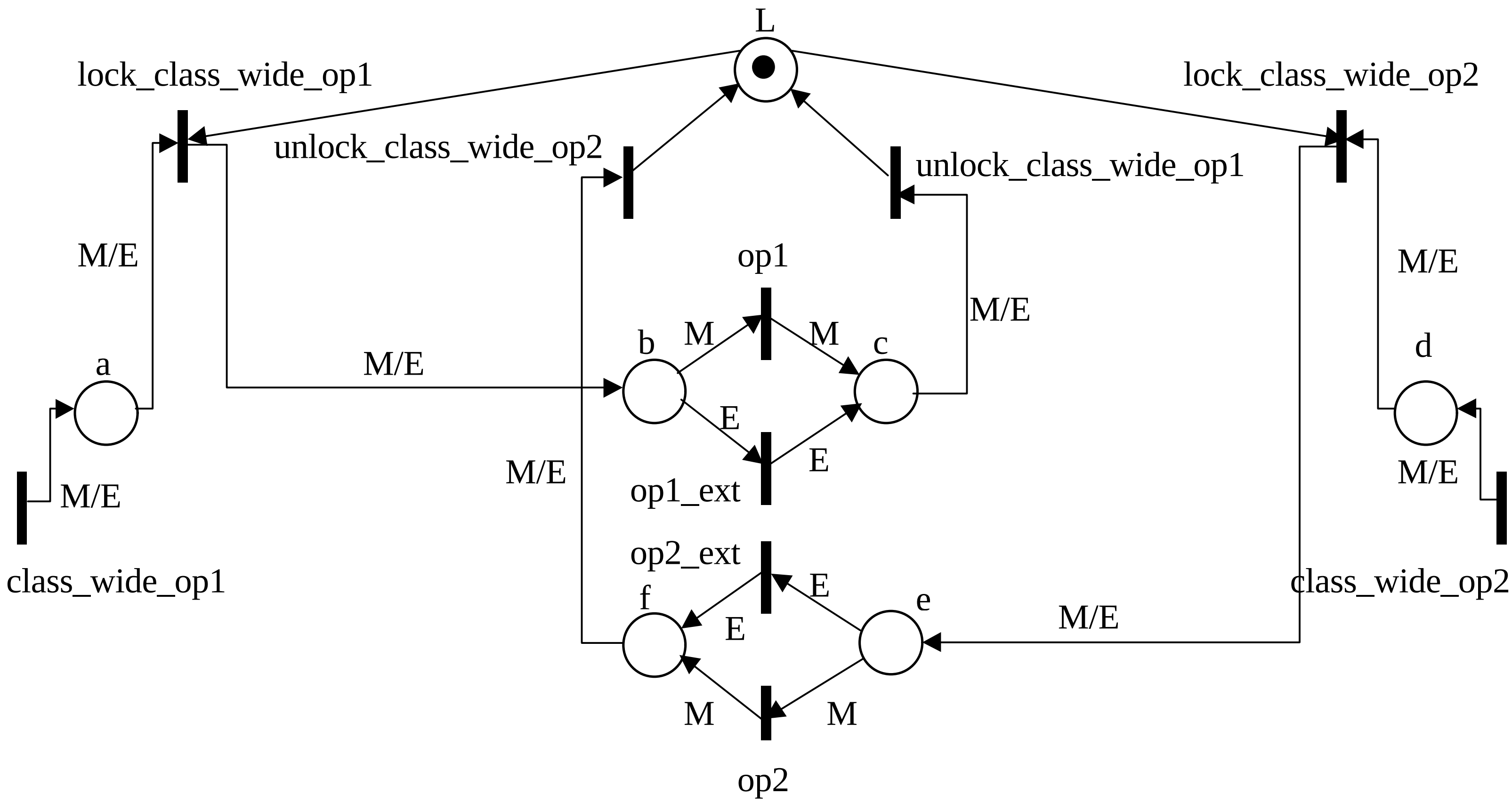


Figure 3. Protected_Object.My_Object.Extended model

Concluding Comments

- Illustrated the possibility of translating advanced features of Ada 95 into Petri net.
- Shown that behavior analysis, such as deadlock analysis, could be automated by using Petri net reachability analysis.
- Performance analysis is possible by using performance Petri net, such as timed Petri net, stochastic Petri net etc.

Definition of Protected Type: Mutex

protected type Mutex **is**
  entry Lock;   **procedure** Unlock;
private
  Release: Boolean := True;
end Mutex;

protected body Mutex **is**
  entry Lock **when** Release **is**
  begin   Release := False;   **end** Lock;
  procedure Unlock
  begin   Release := True;   **end** Unlock;
end Mutex;